EXAMINING THE IMPACT OF LARGE FREIGHT VEHICLES ON SIGNALISED INTERSECTION OPERATION

MANDY HALDANE, BE (Civil) (Hons)

Senior Engineer (Heavy Vehicle Management), Queensland Department of Main Roads

JONATHAN BUNKER, BE (Civil) (Hons), PhD

Lecturer, School of Civil Engineering, Queensland University of Technology

ABSTRACT

Over the last decade, longer, heavier and more powerful multi-combination vehicles (MCVs) have been permitted to use certain road freight routes in Australia, including those with signalised intersections. This paper documents field tests conducted to measure through passenger car equivalences (PCEs) of three MCVs used in Queensland in the simulated environment of a signalised intersection. The results demonstrate that PCE increases with vehicle mass, implying that MCVs may have a potentially greater impact upon signalised intersection operation than would be determined when assuming a standard heavy vehicle PCE of 2 for the through movement. There may be a need to distinguish between the combinations that comprise the heavy vehicle spectrum when assessing MCV routes on corridors with signalised intersections.

Results demonstrate that less intersection time would be used in carrying a given payload when using larger, more freight-efficient MCVs. However, other operational parameters must also be examined, including vehicle paths, sight lines, signal setting requirements, and pavement damage. Further, perceptions of road users and affected communities must be addressed. Results also demonstrate that larger MCVs are more efficient in terms of overall intersection queue storage requirements in carrying a given freight task. Notwithstanding, queue storage requirements of individual MCVs must be addressed in isolation due to their length. The findings of this work will be informative to analysis of signalised intersection operation on designated MCV routes in Australia.

1 INTRODUCTION

The Australian transport industry is moving towards improved road freight efficiency and competitiveness through the use of larger and more innovative vehicle combinations. However, this move has brought about concern over the interaction of these innovative vehicles with existing infrastructure and other road users.

In a review of current literature on the impacts of multi-combination vehicles (MCVs) on traffic operation and safety, Haldane and Bunker (2002) identified that, while the performance characteristics of most MCVs are well documented and verifiable through field trials, the interaction with other road users and effect on traffic operation are not so well understood. It was also recognised that the relationship between MCVs and other road users influences traffic operation measures such as saturation flow, passenger car equivalence, traffic efficiency, and queue lengths.

Saturation flow rate on a movement at a signalised intersection is the maximum constant departure rate of vehicles from a queue during the green light period (Akcelic 1989). It is a function of the intersection basic environment class, lane type, lane width, grade, as well as the volume and through passenger car equivalence (herein termed PCE) of each vehicle type present.

Akcelic (1989) suggests a PCE of 2 for a heavy vehicle moving straight through a signalised intersection. This value implicitly assumes a level grade and standard lane width. A heavy vehicle was defined as any vehicle with more than two axles or with dual tyres on the rear axle. Thus buses, trucks, and semi-trailers, whether loaded or empty, were classified as heavy vehicles. PCE values for other movement types were also suggested.

Over the last decade, heavy vehicle combinations have increased in number, length, mass, and engine power. This may potentially be rendering standard PCE values used in signalised intersection analysis less reflective of heavy vehicle spectra that may incorporate the new and innovative MCVs coming into operation on Australian roads. Queensland University of Technology (QUT) and Queensland Department of Main Roads (QDMR) conducted research to measure PCE values for various MCVs to inform signalised intersection operation analysis. The findings are documented in this paper. The traffic efficiency of MCVs is also examined through measures related to PCE.

2 FIELD TEST DETAILS

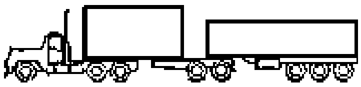
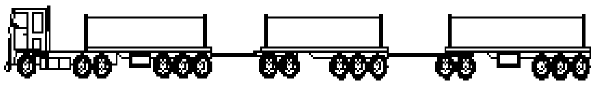
QUT developed an infield test program, with assistance from QDMR and Queensland Transport (QT), for simulating the operation of vehicles departing a queue on a through movement at a signalised intersection, in order to measure PCE for various test vehicles.

2.1 TEST LOCATIONS AND VEHICLES

Vehicle operational data was collected via two in-field test programs located on a controlled road section south of Charters Towers, North Queensland, and at the QT Mount Cotton Training Centre, south-east of Brisbane, between April and July 2001.

Various passenger cars ranging from full size station wagons to compact hatchbacks were tested to obtain base traffic performance data. Three MCVs were tested, whose dimensions and masses are described in Table 1. Each MCV had a width of 2.5 m. Laden test masses were established in the tests to be close to, but within the allowable Gross Combination Mass (GCM).

Table 1: Details of MCVs Tested

Pictorial Representation of Test Vehicle	Test Length (m)	Allowable GCM (t)	Test Mass (t) Unladen (Tare)	Test Mass (t) Laden	Test Payload (t)
B-Double 	22.84	59	32.28 (19.48) †	52.54	33.06
B-Triple 	29.69	75.5	51.25 (25.65) ‡	71.86	46.21
Triple Road Train 	40.70	115.5	44.34	115.00	70.66

† 1st trailer contained a permanent concrete block weighing 12.80t. Unladen test mass 32.28t. Tare mass 19.48t.

‡ 1st and 2nd trailers contained permanent concrete blocks weighing 26.60t. Unladen test mass 51.25t. Tare mass 25.65t.

The B-Double test combination comprised of a tandem-drive prime mover, with 50:50 drive torque distribution, towing tow trailers that were B-coupled. The prime mover was a 1995 Western Star Heritage Series with 18-speed transmission rated at 500 horsepower (373 kW).

The B-Triple test combination comprised of a tandem-drive prime mover, with 50:50 drive torque distribution, towing three trailers, which were B-coupled. The prime mover was a 1995 Western Star Heritage Series with 18-speed transmission rated at 500 horsepower (373 kW).

The Triple Road Train combination comprised of a tandem-drive prime mover, with 50:50 drive torque distribution, towing three side tipper trailers on converter dollies. The prime mover was a 1985 Kenworth SAR with 15-speed transmission rated at 400 horsepower (298 kW).

2.2 VEHICLE INSPECTION

Prior to testing, all relevant vehicle information including dimensions, ratings, laden/unladen GCM, axle masses, and the relevant specifications were recorded. The various components and systems were inspected for leaks, cracks, and alignment to ensure that the vehicle was ready for testing. The manufacturer's specifications were examined to ensure that the combination met all relevant Australian Design Rule regulations and that the components met all necessary specifications.

2.3 TEST PROCEDURE

The objective of the test was to determine the PCEs of a number of test vehicles. The test was restricted to simulate optimal traffic conditions, being straight through movements on a flat grade with no traffic lane width constraints.

Two lines were painted on the road surface 35 m apart. This distance simulated five vehicles in a queue. Akcelik *et al.* (1999) advised that the queue space for a single passenger car is 7.0 m. The lines were clearly labelled ‘0’ and ‘35’.

The test was initially conducted with passenger cars only, to determine the average passenger car saturation headway, which is the inverse of saturation flow rate. A passenger car was positioned with the front of the vehicle on the first painted line marked ‘0’. A second passenger car was positioned behind the first vehicle as shown in Figure 1 below. The first passenger car accelerated from a standing position under standard operating acceleration, as if accelerating from a signalised intersection behind a queue of five cars. The second passenger car followed the first passenger car, also operating under standard operating acceleration.

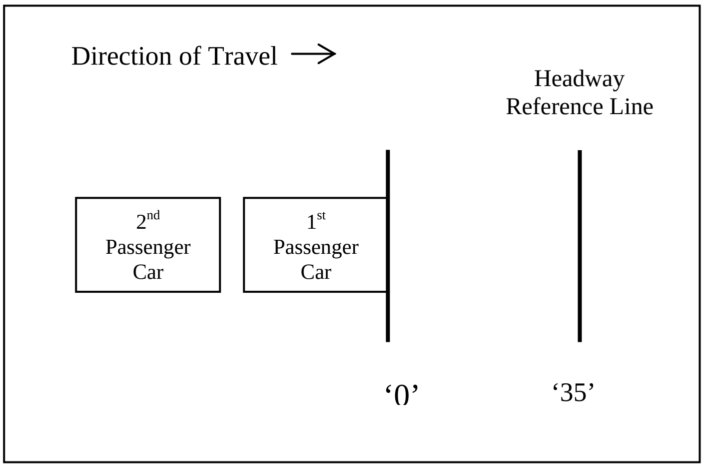


Figure 1: Initial Position of Passenger Cars (PCE of Cars)

It is recognised that this representation does not reflect reverse shockwave propagation in an accelerating queue. To attempt to counteract this influence the first passenger car operators were instructed to accelerate conservatively as if they were in-queue.

A reference clock was started at zero when the first passenger car was released. The time, in seconds, was recorded as the noses of each of the first and second passenger cars crossed the second painted line, simulating the stop line, marked ‘35’. The time between the two arrivals over the stop line was used to represent the saturation headway. At least five successful trials were performed to determine the average saturation headway and standard deviation of saturation headway. Different driver combinations were used each time to ensure individual driver characteristics did not distort results.

The test was then repeated with each test MCV (laden and unladen) positioned between the passenger cars as illustrated in Figure 2, to obtain test vehicle saturation headways. The first passenger car accelerated from a standing position under standard operating acceleration, as if accelerating at a signalised intersection behind a queue of five cars. The test vehicle followed the first passenger car, and the second passenger car followed the test vehicle, both also operating under standard operating acceleration.

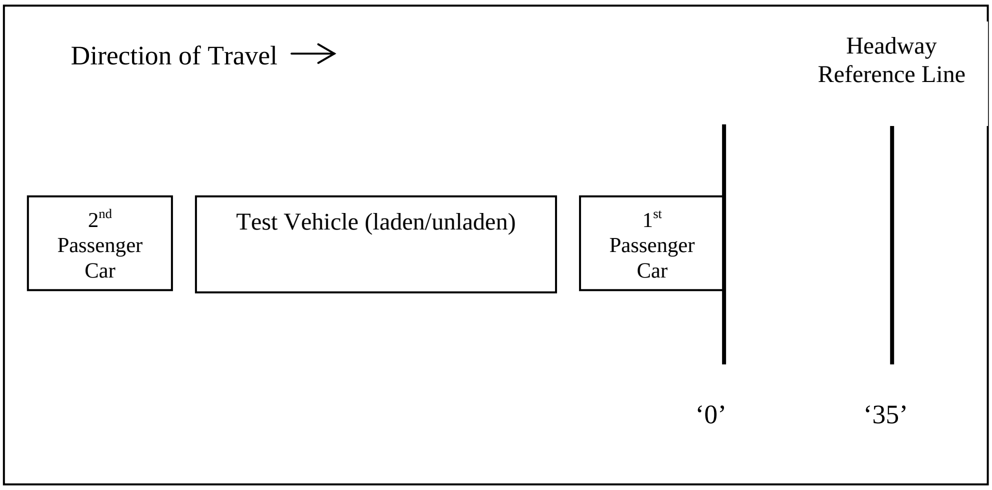


Figure 2: Initial Position of Passenger Cars & Test Vehicle (PCE of Test Vehicle)

The time headway measured between the arrival of the passenger cars over the '35' line incorporates the headway characteristics of the test vehicle plus that of the second passenger car. Under repeated trials, the average saturation headway of the test vehicle alone could then be estimated by deducting the average passenger car saturation headway.

Aside from the laden Triple Road Train, at least five successful trials were performed for each test vehicle under laden and unladen conditions; with different driver combinations each time to ensure driver characteristics did not distort the data. Two successful trials only were performed with the Triple Road Train, due to failing light conditions.

3 PASSENGER CAR EQUIVALENCE TESTS

3.1 PCE TEST RESULTS

For each test vehicle, the saturation headway statistics and PCE were estimated from the test results. The results, arranged in order of increasing PCE, are shown in Table 2, along with each vehicle's tested length and mass.

The saturation flow rate is equal to the reciprocal of the mean saturation headway. The value for passenger cars, calculated from the test result in Table 2, is 0.50 pc/s. This is very close to the ideal saturation flow rate of 0.53 pc/s, or 1,900 pc/h, quoted in the Highway Capacity Manual (TRB 1998), and matches the value of 0.5 pc/s commonly used in Australian practice.

PCE is a non-dimensional measure of time duration, which incorporates the time required for the vehicle to clear the stop line, plus part of the buffers between the vehicle and each of the preceding and trailing vehicles. It can be shown theoretically that time duration, when moving a certain distance during the acceleration process, increases as a function of mass, for a given deliverable power. This is apparent within the results of Table 2, where PCE increases with test mass for prime movers of similar deliverable power.

Comparison between the laden and unladen B-Double demonstrates the influence of test mass on PCE. The only physical difference between the two test vehicles was test mass; the laden B-Double was approximately 63% heavier. This resulted in a PCE 19% higher.

Table 2: Test Vehicle Characteristics and Intersection Operation Test Results

Test Vehicle	Tested Length (m)	Tested Mass (t)	Saturation Headway (s)		PCE
			Mean	Standard Deviation	
Passenger Car	4.96	1.53	2.01	0.49	1.00
Unladen B-Double	22.84	32.28	9.38	0.61	4.66
Unladen Triple Road Train	40.70	44.34	9.53	1.03	4.74
Laden B-Double	22.84	52.54	11.15	0.60	5.55
Unladen B-Triple	29.69	51.25	11.44	0.66	5.69
Laden B-Triple	29.69	71.86	13.61	0.65	6.77
Laden Triple Road Train	40.70	115.0	14.97	1.02	7.45

The influence of MCV length is partly implicit within its mass, as longer vehicles have a higher self mass and are capable of carrying a greater payload. Notwithstanding, it is useful to isolate the length effect by considering MCVs of similar mass and power, but different lengths. The longer vehicle would be expected to take marginally longer to cross the stop line and thereby have a higher PCE. A comparison between results for the laden B-Double and unladen B-Triple, both of similar test mass and engine power, reveals that, although the B-Triple was 23% longer, the PCE value was only slightly higher, equivalent to 0.3s or 2.5%. This suggests that the influence of vehicle length is less pronounced than that of mass.

3.2 APPLICATION OF PCE VALUES

The high PCEs of MCVs imply that they may have a potentially greater impact upon signalised intersection operation than would be determined from analysis when assuming a standard heavy vehicle PCE of 2 for the through movement. Consequently, there may be a need to distinguish between the different combinations that comprise the heavy vehicle spectrum, in order to estimate the average PCE of all heavy vehicles. This becomes particularly important when assessing or gazetting MCV routes on corridors with signalised intersections.

Table 3 summarises ranges that may be useful in estimating PCEs across a heavy vehicle spectrum. It is noted that the values are for through movements only. Further testing is required to establish PCEs for Double Road Trains, AB-Triples, and AAB-Quad combinations. Further testing is also required to establish values for turning movements, and to examine the effects of grade and lane width.

Table 3: Heavy Vehicle Types and PCE Ranges for Through Movements

Vehicle Type	Through Movement PCE Range (Tare – Gross)
Rigid truck, bus, coach	0.67 – 2.88 †
Semi-trailer, rigid truck towing trailer	2.52 – 4.82 †
B-Double (23m)	3.68†† – 5.55
Double Road Train	Future testing required
B-Triple (30m)	4.12†† – 6.77
AB-Triple	Future testing required
Triple Road Train (41m)	4.74 – 7.45
AAB-Quad	Future testing required

† After Cuddon and Ogden (1992)

†† Estimated for true tare mass

As heavier MCVs produce these higher PCE values, in significant volumes they may increase the average PCE of heavy vehicles, thereby reducing the saturation flow rate at a signalised intersection. In absolute terms, this may increase degree of saturation and delay to all traffic, thereby decreasing the efficiency of the intersection. However, in relative terms, this may not be the case when considering alternative combinations tasked with carrying a given volume of freight. This is now discussed.

3.3 TRAFFIC EFFICIENCY

The traffic efficiency of each test vehicle was ascertained from the PCE values determined from testing. The results are displayed in Table 4, along with the estimated value for a 6 axle semi-trailer.

Table 4: Traffic Efficiency for each Laden Test Vehicle

Test Vehicle (Laden)	Traffic Efficiency (Payload t/PCE)
6 axle semi-trailer (19m) †	5.6
B-Double (23m)	6.0
B-Triple (30m)	6.8
Triple Road Train (41m)	9.5

† estimated using PCE value of 4.82 after Cuddon and Ogden (1992) and 27t allowable payload

The results in Table 4 demonstrate that the Triple Road Train was more traffic-efficient in payload terms than the B-Triple, and the B-Double, which in turn would be more traffic-efficient than a 6 axle semi-trailer. This reflects that less intersection time would be used in carrying a given payload when using larger, more freight-efficient MCVs.

This may be demonstrated further from a whole-of-task context by considering the number of journeys required by each laden vehicle type to transport 1,000 tonnes of freight from Point A to Point B. Using the payload values from Table 1 and the PCEs from Table 2, the number of MCV journeys, and PCEs should these movements pass straight through a given signalised intersection between Point A and Point B, are provided in Table 5. Values calculated for a 6 axle semi-trailer are included for comparison. It is clear from this example that larger MCVs use less intersection time to carry a given freight task.

Table 5: Movements and PCEs of Various Test Vehicles Carrying 1,000t of Freight

Test Vehicle (Laden)	Movements to transport 1,000t	Intersection PCEs
6 axle semi-trailer (19m) †	37	178
B-Double (23m)	31	172
B-Triple (30m)	22	149
Triple Road Train (41m)	15	112

† estimated using PCE value of 4.82 from Cuddon and Ogden (1992) and 27t allowable payload

It is important to note that other intersection-related operational parameters must also be examined in a thorough comparison, including queue storage, vehicle paths, sight lines, signal setting requirements, and pavement damage. Queue storage is discussed below. Further, perceptions of road users and affected communities must be addressed.

4 MCV QUEUE LENGTH EFFECTS

The queue length effect of MCVs at signalised intersections may be addressed through the measures of passenger car queue equivalence and ratio of allowable payload per metre of queue length. The results for each measure are displayed in Table 6.

Table 6: Queue Length Equivalency and Tonnage Transported per Metre Ratio

Test Vehicle	Measured Av. Queue Length (m)	Allowable Payload (t)	Passenger Car Queue Equivalence	Allowable Payload / Queue Length (t/m)
6 axle semi-trailer (19m)	23.3	27.0	3.3	1.16
B-Double (23m)	27.1	39.5	3.9	1.46
B-Triple (30m)	34.0	49.9	4.9	1.47
Triple Road Train (41m)	45.0	71.2	6.4	1.58

The measured average queue length consists of the length of the test vehicle plus the distance between the rear of the test vehicle and the nose of the next vehicle in queue. Consequently, this measure is partially influenced by driver behaviour. The passenger car queue equivalence of each test vehicle is included for reference as a non-dimensional measure of its queue length.

The ratios of allowable payload per metre of queue length indicate that, although a Triple Road Train takes up twice the queue length of a semi-trailer, a greater payload may be stored per metre of queue, rendering the Triple Road Train more efficient in terms of storage requirements in carrying a given freight task. The efficiencies of longer vehicle combinations are mainly attributed to the lower proportion of total vehicle length taken up by the prime mover and the incidence of fewer spaces between vehicles.

It must be noted that, although queue lengths may be lower overall for larger MCVs in carrying a given freight task, queue storage requirements of individual MCVs must be addressed in intersection analysis. For instance, long MCVs may block entry to adjacent lanes thereby reducing their utilisation, and short lanes for movements containing MCVs may not be sufficiently long to accommodate them, also reducing their utilisation. This necessitates a case by case investigation when considering signalised intersections on candidate routes.

5 CONCLUSIONS

This paper documented the results of field tests of multi-combination vehicle (MCV) operation in the simulated environment of a signalised intersection. The results demonstrated that the through passenger car equivalence (PCE) of MCVs increases with vehicle mass.

The increase in PCE with vehicle mass implies that MCVs may have a potentially greater impact upon signalised intersection operation than would be determined from analysis when assuming a standard heavy vehicle PCE of 2 for the through movement. Consequently, there may be a need to distinguish between the combinations that comprise the heavy vehicle spectrum, in order to estimate a better representative average PCE of all heavy vehicles. This becomes particularly important when assessing or gazetting MCV routes on corridors with signalised intersections. The PCE ranges provided in Table 3, which include values previously quoted for conventional heavy vehicles, augmented by values determined for the new, larger MCVs from this research, may be used to estimate the average PCE across the spectrum for through movements under standard conditions.

Further testing is required to establish PCEs for Double Road Trains, AB-Triples, and AAB-Quad combinations. Further testing is also required to establish values for turning movements, and to examine the effects of grade and lane width.

Test results were used to demonstrate that less intersection time would be used in carrying a given payload when using a larger, more freight-efficient MCV. However, other intersection-related operational parameters must also be examined in a thorough comparison, including vehicle paths, sight lines, signal setting requirements, and pavement damage. Further, perceptions of road users and affected communities must be addressed.

Test results were also used to demonstrate that larger MCVs are more efficient in terms of overall intersection queue storage requirements in carrying a given freight task, which is mainly attributed to the lower proportion of total vehicle length taken up by the prime mover and the incidence of fewer spaces between vehicles. Notwithstanding, queue storage requirements of individual MCVs must be addressed in isolation due to their length. This necessitates a case by case investigation when considering signalised intersections on candidate MCV routes.

The findings of this work will be informative to analysis of signalised intersection operation on designated MCV routes in Australia.

6 ACKNOWLEDGEMENTS

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